Heated Ascorbic/Citric Acid Solution as Browning Inhibitor for Pre-Peeled Potatoes

ABSTRACT

Treatment of pre-peeled potatoes with heated ascorbic acid (AA)/citric acid (CA) solution to extend shelf-life was investigated. Potatoes were abrasion or high pressure steam peeled, heated for 5–20 min in 1% AA + 2% CA at 45–55°C, cooled, and then dipped for 5 min in browning inhibitor (BI) solution containing 4% AA + 1% CA + 1% sodium acid pyrophosphate. Combined treatment inhibited potato discoloration for 14 days at 4°C, compared to 3-6 days with BI treatment alone. Raw material and treatment conditions were selected to minimize graying and textural abnormalities encountered with some treatments. Treatment with heated AA/CA may be an alternative to use of sulfites to control browning in pre-peeled potatoes.

Key Words: potatoes, browning, ascorbic acid, citric acid, pre-peeling

INTRODUCTION

SULFITES are highly effective in controlling enzymatic browning of pre-peeled potatoes (Feinberg et al., 1987). Because of adverse health effects, however, use of sulfites for this purpose has been criticized (FDA, 1990), although sulfiting of pre-peeled potatoes is still permitted (FDA, 1994). Several sulfite substitutes, mostly formulations of ascorbic acid (AA) or erythorbic acid (EA) in combination with citric acid (CA), phosphates, preservatives, and other adjuncts (Duxbury, 1987; Langdon, 1987; Santerre et al., 1991), have been tested, but these were not as effective as sulfites, and alternative means of inhibiting browning in pre-peeled potatoes are needed. Various other means of inhibiting browning in potatoes include use of vacuum or modified atmosphere packaging (O'Beirne and Ballantyne, 1987; Langdon, 1987), packing in citric acid solution after application of browning inhibitors (Santerre et al., 1991), digestion with strong mineral acids (Schwank, 1992; Sperber, 1992), and application of experimental browning inhibitors such as sulfur amino acids (Molnar-Perl and Friedman, 1990), 4-hexylresorcinol (McEvily et al., 1992), and AA-2-phosphates (Sapers and Miller, 1992). We reported that lye digestion of the peeled potato surface, prior to application of a conventional AA-based browning inhibitor, controlled product discoloration for 13-15 days at 4°C (Sapers and Miller, 1993). Digestion removed the unstable surface tissues that were mechanically or thermally disrupted by peeling.

In a preliminary comparison of procedures alternative to lye digestion (Sapers and Miller, 1991), we observed that immersion of peeled potatoes in a solution of AA and CA, heated to 45–65°C, followed by application of a browning inhibitor dip, removed no surface tissue but was more effective in controlling browning than other treatments studied. These results implied that tyrosinase in disrupted cells at the peeled surface might be partially inactivated by the combination of mild heating and exposure to the added acids. Such principle might provide the basis of a new method for controlling enzymatic browning in pre-peeled potatoes. Therefore, our objective was to determine whether a practical treatment to control enzymatic browning in pre-peeled potatoes, based on heating in AA and CA solution, could be developed.

MATERIALS & METHODS

RUSSET AND ROUND-WHITE TYPES of potatoes were obtained from a local distributor and held at 4°C or conditioned at 20°C for 1–4 wk prior to processing. Potatoes were abrasion peeled with a Toledo Vegetable Peeler (Model A1-15; Toledo Scale Co., Toledo, OH); high pressure steam peeled at 1400 kPa for 15.5 sec, followed by cooling in cold water; or lye peeled for 3 min in 17% NaOH at 88°C, followed by cooling with cold water and removal of digested peel by brushing. Peeled potatoes were stored briefly in a solution containing 2% sodium acid pyrophosphate (SAPP) and 0.25% NaCl to prevent darkening until further treatments could be applied.

Samples comprising two or three peeled tubers were immersed for 5–20 min in 2L of a solution containing 0–2% AA, 0–2% CA, and, in some experiments, 0.1% $CaCl_2$, 0.5–1% SAPP, or 200–1000 ppm EDTA (disodium-calcium salt), heated to 45–65 ± 2°C. Treatment was carried out on a steam bath in 3L beakers. A 138 mm diam porcelain dessicator plate, with five 30-mm diam holes, was placed at the bottom of each beaker to prevent direct contact between potatoes and the hot glass surface. The potatoes were stirred periodically with a large plastic spoon to ensure temperature uniformity as well as uniform exposure of all surfaces. After treatment, potatoes were placed in a collander and cooled in running tap water for 2 min.

Treated potatoes and controls were dipped in a browning inhibitor solution containing 4% AA, 1% CA, 1% SAPP, and in some experiments, 0.1–0.2% $CaCl_2$ (added to improve texture; see O'Beirne and Ballantyne, 1987; Duxbury, 1988; Santerre et al., 1991) for 5 min, with stirring, and then drained in a collander. In those experiments where potato color was to be measured by tristimulus colorimetry, duplicate plugs from treated and control tubers were cut with an electric cork borer, as described (Sapers and Miller, 1992) and immediately dipped in browning inhibitor solution.

Following application of browning inhibitor dips, whole potatoes were packaged in 3.8L plastic food storage bags (Baggies®, Mobil Chemical Company, Consumer Products Div., Pittsford, NY), punctured twice with an awl to preclude development of anaerobic conditions during storage, and were stored at 4°C for up to 2 wk. Plugs were placed in glass crystallizing dishes, covered with plastic Petri dish lids, and also stored at 4°C.

Treated potatoes and controls were observed during storage for development of brown, gray or black discolorations. Ratings of samples for discoloration (degree of browning or graying), carried out by the investigators, represented consensus scores and considered tuber-to-tuber variation within samples. Hunter L- and a-values at the peeled surface of potato plugs were measured with a Gardner XL-23 tristimulus colorimeter, as described (Sapers and Miller, 1992). Changes in L- and a-values during storage ($\Delta L = L_{ST} - L_0$, and $\Delta a = a_{ST} - a_0$), associated with enzymatic browning in previous studies (Sapers and Miller, 1993), were calculated from tristimulus data. Mean ΔL and Δa values for replicate plugs from each treatment were compared by the Bonferroni LSD mean separation test (Miller, 1981).

Relationships between potato decay, iron contamination, AA degradation in treatment solutions, and graying of treated potatoes were examined by heating good quality or decayed abrasion-peeled Russet potatoes for up to 6 hr at 55°C in solutions containing 1% AA + 2% CA, with or without 1 ppm Fe, added as ferrous sulfate or ferric chloride. Aliquots of treatment solutions were removed at hourly intervals for AA determination by the 2,6-dichloroindophenol titrimetric method (AOAC, 1990). In addition, the extent of graying was determined in abrasion-peeled round-white potatoes, prepared from good quality raw material or tubers showing decay, that had been heated in 1% AA + 2% CA for 15 min at 55°C and then dipped in browning inhibitor solution.

Table 1—Effect of combined treatment with heated ascorbic acid/citric acid solution and browning inhibitor dip on discoloration of abrasion peeled potatoes at 4°C

Potato	Digestion[a]	Browning inhibitor dip[b]	ΔL Day 5/6	ΔL Day 8/9	ΔL Day 12/13	Δa Day 5/6	Δa Day 8/9	Δa Day 12/13	Appearance[f] Day 5/6	Appearance[f] Day 8/9	Appearance[f] Day 12/13
Russet	None	No	-22.1^{e}	-23.0^{e}	-23.6^{e}	5.8^{e}	6.6^{e}	7.0^{e}	+++	+++	++++
	None	Yes	-2.2^{d}	-6.8^{d}	-8.3^{d}	1.6^{d}	4.4^{d}	5.6^{d}	++	++/+++	+++
	1% AA + 1% CA	Yes	3.0^{c}	2.4^{c}	1.2^{c}	0^{c}	0.3^{c}	1.7^{c}	–	–	–/+++
	1% AA + 2% CA	Yes	2.4^{c}	1.6^{c}	0.0^{c}	0^{c}	0.2^{c}	1.6^{c}	–	–	–
	1% AA + 2% CA + 1% SAPP	Yes	0.9^{c}	0.8^{c}	-1.2^{c}	0^{c}	0.3^{c}	2.1^{c}	–	–	+
Round-white	None	No	-18.9^{e}	-21.3^{e}	-23.2^{e}	5.3^{d}	5.8^{d}	6.2^{d}	+++	+++	+++
	None	Yes	-9.6^{d}	-11.8^{d}	-14.6^{d}	4.0^{d}	5.1^{d}	6.2^{d}	++/+++	+++	+++
	1% AA + 1% CA	Yes	-1.3^{c}	-1.3^{c}	-2.6^{c}	0.8^{c}	0.8^{c}	1.2^{c}	–/+++	–/+++	–/+++
	1% AA + 2% CA	Yes	0.5^{c}	0.5^{c}	0.5^{c}	0.1^{c}	0.2^{c}	0.5^{c}	–	–	–
	1% AA + 2% CA + 1% SAPP	Yes	0.2^{c}	0.3^{c}	0.2^{c}	0.2^{c}	0.4^{c}	0.7^{c}	–	–	–

[a] 15 min at 55°C. AA = ascorbic acid; CA = citric acid; SAPP = sodium acid pyrophosphate.
[b] min dip in 4% AA + 1% SAPP + 0.2% $CaCl_2$.
[c-e] Means for six to eight plugs/treatment; means within columns, followed by different superscripts, are significantly different at $P < 0.05$ by the Bonferroni LSD test.
[f] Severity of discoloration: + + + +, very severe; + + +, severe; + +, moderate; +, slight; –, none.

Table 2—Factors affecting graying of abrasion-peeled potatoes treated with heated AA/CA solution and browning inhibitor dip during storage at 4°C[a]

Expt	Potato	Factor	Occurrence of Graying[b]
A	Round-white	Good condition	–/+
		Poor condition	+++
B	Russet	Indirect heating, stirred	–
		Direct heating, stirred	+/++
		Direct heating, not stirred	++/+++
C	Russet	Tubers not dropped	–
		Tubers dropped before digestion	+/+++
		Tubers dropped after digestion	+++
D	Round-white	Stored 1 wk at 4°C	–/+++
		Stored 1 wk at 20°C	–
		Stored 3 wk at 4°C	–/+++
		Stored 3 wk at 20°C	–

[a] Heated 15 min at 55°C in 1% AA + 2% CA; dipped 5 min in 4% AA + 1% CA + 1% SAPP + 0.2% $CaCl_2$. See Table 1, Footnote 1, for explanation of abbreviations.
[b] + + +, severe; + +, moderate, +, slight; –, none; –/+ + +, variation from none to severe.

Involvement of bruising in the development of graying was examined by intentionally bruising abrasion-peeled Russet and round-white potatoes by dropping them 5 times from a height of 1.5 m in a 10 cm diameter PVC pipe. Peeled potatoes were bruised either before treatment with heated AA/CA solution or after this treatment and before application of the browning inhibitor dip.

Textural attributes of treated potatoes were evaluated by boiling samples comprising 2 tubers/treatment in 2L tap water in 3L stainless steel pots on an electric range until fully cooked (25–35 min). Heating conditions were carefully controlled, and potatoes were stirred every 2.5–3 min to ensure uniform cooking. Some treatments resulted in formation of a thick shell of toughened tissue, which separated from underlying tissue when the cooked potato was cut and was difficult to mash. Therefore, cooked potatoes were examined by the investigators for thickness of this layer, occurrence of separation, toughness of the layer when chewed, and ease of mashing with a fork. Qualitative assessments of these defects were made considering tuber-to-tuber variation within samples. However, no attempt was made to rate the degree of separation or toughness in these tests.

RESULTS & DISCUSSION

Control of browning by treatment with heated AA/CA solutions

Preliminary results demonstrating the effectiveness of treatment with heated AA/CA solutions in controlling browning were confirmed with abrasion-peeled Russet and round-white potatoes. They had been immersed for 15 min in 1% AA and 1 or 2% CA, with or without 1% SAPP, at 55°C and then dipped in a browning inhibitor solution (Table 1). Both untreated controls and controls treated only with browning inhibitor dip showed large decreases in L-value, indicative of darkening, and increases in a-value, indicative of browning. ΔL- and Δa-values for samples treated in heated solutions containing AA and both levels of CA were similar and much lower than those for controls. A nonuniform grayish-black discoloration, resembling after-cooking darkening (Smith, 1987) was visible on some samples. Visual observation indicated more severe graying at the lower CA level. Addition of SAPP to the heated solution had little or no effect on the ΔL- or Δa-values or sample appearance. Variation in darkening was seen between replicates, indicating a nonuniform response of potato surfaces to treatment. In some cases, gray or black discolorations could clearly be distinguished from browning, even on the same tuber.

The most likely mechanism for inhibition of discoloration by digestion treatment is partial inactivation of tyrosinase by the combination of heat and acidity, as suggested by the work of Schwank (1992). AA also might react directly with tyrosinase, resulting in enzyme inactivation (Golan-Goldhirsh and Whitaker, 1984) and/or reduce quinones, generated by tyrosinase-catalyzed oxidation of phenolic substrates, back to polyphenols (Vamos-Vigyazo, 1981). In addition, some leaching of tyrosinase, and its substrates may occur at the peeled surface during treatment.

Causes of localized graying of treated potatoes

Since graying represented a major defect of treated potatoes, several hypotheses explaining causes of this discoloration were tested so that the defect might be avoided. An examination of AA degradation during treatment showed that no significant losses of AA occurred in treatment solutions containing either good quality or decayed potatoes, even after 6 hr at 55°C. Similar results were obtained when good quality potatoes were heated in AA/CA solutions containing 1 ppm Fe^{++} or Fe^{+++}, postulated as potential contaminants of the raw material or equipment. Thus, AA instability was not likely a factor affecting development of localized gray areas.

In further experiments, abrasion-peeled round-white potatoes, that had been prepared from raw material showing decay and given the heated AA/CA treatment and browning inhibitor dip, showed more severe graying than product prepared from good quality raw material (Table 2, Expt. A). This may have been due to composition changes resulting from decay, bruising, or senescence, i.e., an elevation in phenolic compounds, or to greater sensitivity to bruising during treatment. Mondy et al. (1987) reported that bruising resulted in greater accumulation of phenolic compounds in Katahdin potatoes.

We next determined whether surface discolorations could have resulted from over-heating of potato surfaces during prolonged contact with the bottom of the beaker during treatment. Russet tubers were heated with no stirring, omission of the desiccator plate, and maximum contact with the beaker bottom. Others were heated with periodic stirring and omission of the desiccator plate, permitting some direct contact with the bottom of the beaker, or with periodic stirring and the desiccator plate

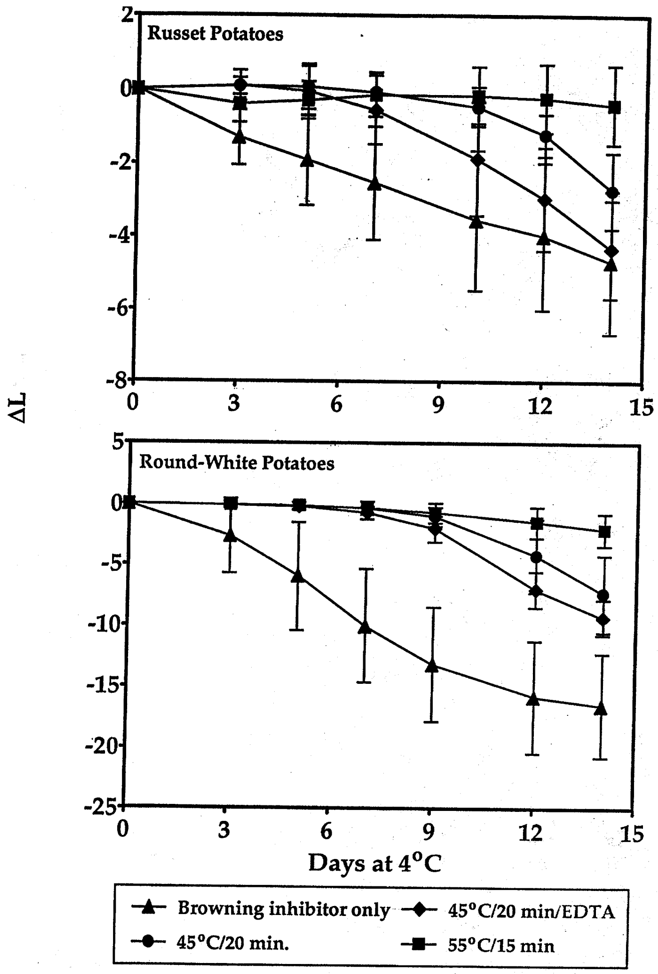

Fig. 1—Change in L-value during storage of plugs from abrasion-peeled Russet and round-white potatoes treated by immersion in heated AA/CA solution and/or application of browning inhibitor dip.

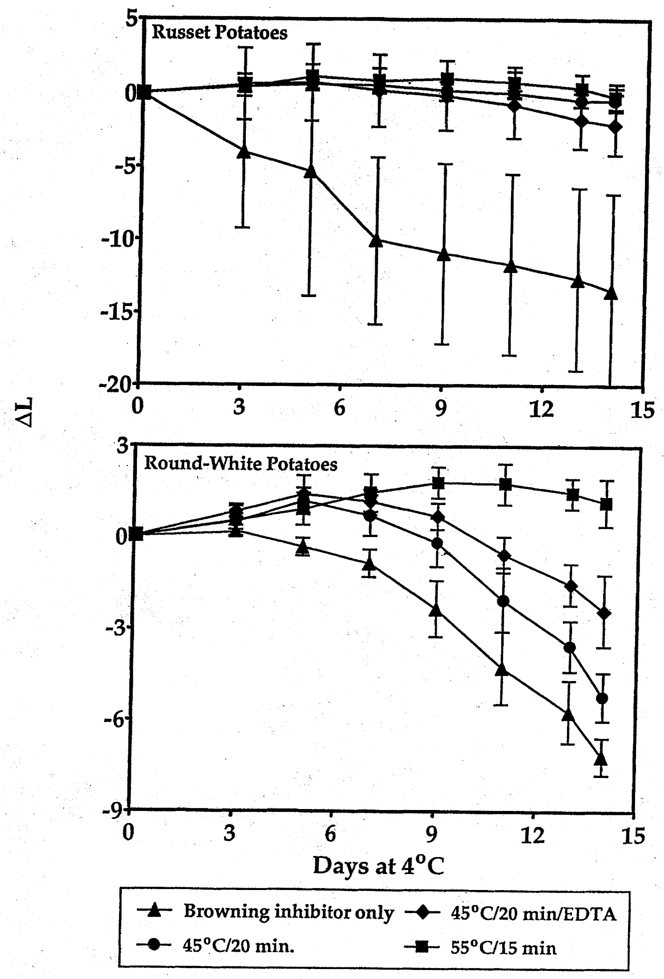

Fig. 2—Change in L-value during storage of plugs from high pressure steam-peeled Russet and round-white potatoes treated by immersion in heated AA/CA solution and/or application of browning inhibitor dip.

Table 4—Effect of combined treatment with heated AA/CA solution and browning inhibitor dip on discoloration of whole pre-peeled potatoes during storage

	Days before discoloration[b]			
	Abrasion-peeled		High pressure steam-peeled	
Treatment[a]	Russet	Round-white	Russet	Round-white
Std browning inhibitor dip	< 3	< 3	1-3	3-5
55°C/15 min + dip	14	14	14	14
45°C/20 min + dip	10-12	12-14	14	14
45°C/20 min with 200 ppm EDTA + dip	14	12-14	14	14

[a] Std browning inhibitor dip = 4% AA + 1% CA + 1% SAPP; AA/CA soln = 1% AA + 2% CA. See Table 1, Footnote 1, for explanation of abbreviations.

[b] Day at 4°C when two of three tubers in sample show at least moderate graying or browning.

subsequent cross-linking by endogenous or added calcium ion, as proposed by Bartolome and Hoff (1972). The toughening effect of citric acid we observed may be related to acidification effects on pectin degradation and firmness observed in blanched carrot tissue (Ben-Shalom et al., 1992) and sweet potato French fries (Walter et al., 1992). It is less likely that the textural effects induced by heat treatment were related to starch gelatinization since lower temperatures were used than are thought to be required for potato starch gelatinization (64–71°C) (Roberts and Proctor, 1955). However, Ju and Reid (1994) obtained evidence for some gelatinization at 55°C but not at 45°C.

Effect of modified conditions on discoloration

Because modification of conditions to avoid toughening might adversely affect product storage stability, plugs from abrasion-peeled potatoes, given alternative treatments were compared during storage at 4°C (Fig. 1). The ΔL values clearly showed that the 55°C/15 min treatment, in combination with the browning inhibitor dip, was more effective than the dip alone, delaying discoloration for at least 14 days. ΔL values also were much less variable for samples given the combination treatment than for those only given the dip. Treatment at 45°C for 20 min, with or without added EDTA, was less effective, delaying discoloration for 6–9 days.

Visual observations of the development of discolorations during storage of whole potatoes were generally consistent with reflectance data obtained with plugs (Table 4). Discrepancies between the two methods of evaluation reflect discolorations at tuber ends which were not measured by colorimetry, and the tendency of plugs to brown more than corresponding whole potatoes. That difference was probably due to the retention of residual dip on peeled surfaces of whole potatoes within the confined space of plastic storage bags. That condition probably more accurately represents the true state of pre-peeled potatoes than the plug system.

Reponse of steam- and lye-peeled potatoes

High pressure steam-peeled Russet and round-white potatoes responded better than abrasion-peeled potatoes to treatment with

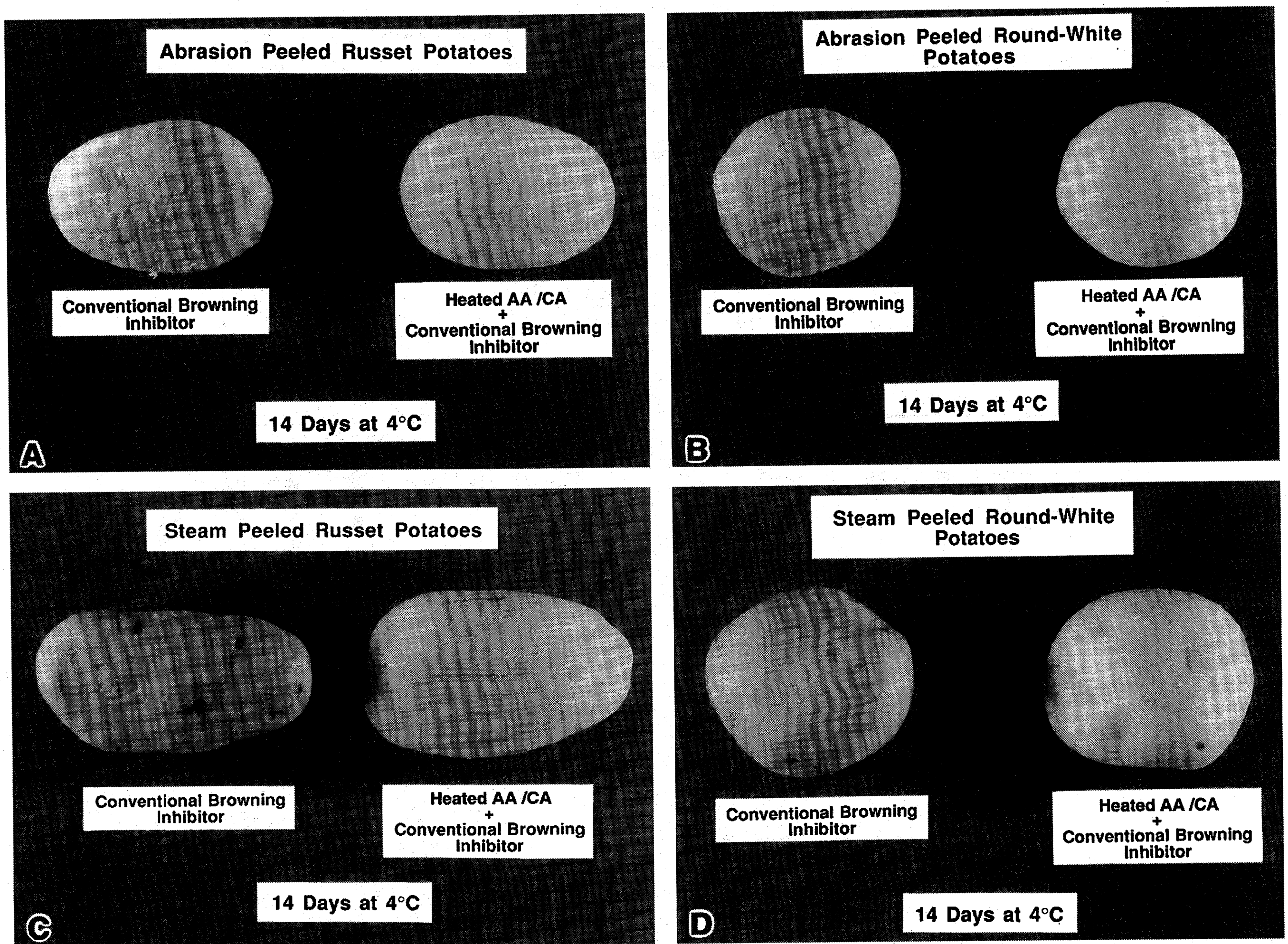

Fig. 3—Pre-peeled potatoes immersed in 1% AA + 2% CA for 20 min at 45°C and/or dipped 5 min in conventional browning inhibitor solution containing 4% AA + 1% CA + 1% SAPP; samples stored at 4°C for 14 days. A, abrasion-peeled Russet; B, abrasion-peeled round-white; C, high pressure steam-peeled Russet; D, high pressure steam-peeled round-white.

heated AA/CA solution, showing smaller decreases in L-values during storage (Fig. 2). Treatment at 55°C was more effective in delaying discoloration of round-white potatoes than treatment at 45°C, with or without added EDTA; the treatments were similar in effectiveness with Russet potatoes. Visual observations confirmed that combination treatments controlled discoloration of high pressure steam-peeled potatoes for at least 14 days at 4°C (Table 4). The absence of significant discolorations in treated tubers can be seen in photographs of abrasion- and high pressure steam-peeled potatoes, treated at 45°C for 20 min, with or without EDTA, after 14 days at 4°C (Fig. 3). Thus, use of the lower treatment temperature to improve texture and ease of mashing would not greatly affect control of discoloration in abrasion- and high pressure steam-peeled potatoes.

Lye-peeled potatoes did not respond as well to treatment with heated AA/CA solution. They developed moderate to severe discolorations between days 5 and 7 with Russet and between days 7 and 9 with round-white while their respective controls, given only the browning inhibitor treatment, failed in 3–5 days (data not shown). Apparently, removal of the unstable "cooked" layer that results from lye peeling, as was done in our lye digestion process (Sapers and Miller, 1993) but not in the present treatment, is required to prevent enzymatic browning or after-cooking darkening reactions at the lye-peeled surface.

CONCLUSIONS

TREATMENT of abrasion- or high pressure steam-peeled potatoes with heated AA/CA solutions, prior to application of an AA-based browning inhibitor dip, prevented discoloration of the peeled surface for up to 14 days at 4°C. Graying of treated surfaces was minimized by use of good quality raw material, storage of raw materials at 20°C, and avoidance of bruising and overheating. Textural abnormalities may be minimized by lower treatment temperatures, addition of EDTA to AA/CA solutions, and omission of calcium. Use of a lower treatment temperature to improve texture might hasten the appearance of discolorations by several days. The heated AA/CA treatment represents a possible alternative to use of sulfites in controlling discoloration reactions of pre-peeled potatoes.

REFERENCES

AOAC. 1990. Vitamin C (ascorbic acid) in vitamin preparations and juices, 967.21. In *Official Methods of Analysis*, 15th ed. Association of Official Analytical Chemists, Washington, DC.
Bartolome, L.G. and Hoff, J.E. 1972. Firming of potatoes: biochemical effects of preheating. J. Agr. Food Chem. 20: 266–270.
Ben-Shalom, N., Plat, D., Levi, A., and Pinto, R. 1992. Influence of pH treatment on pectic substances and firmness of blanched carrots. Food Chemistry 44: 251–254.
Duxbury, D.D. 1987. Preservative blend extends storage life of fresh potatoes. Food Process. 48(5): 84–85.
Duxbury, D.D. 1988. Stabilizer blend extends shelf life of fresh fruit, vegetables. Food Process. 49(9): 98–99.
FDA. 1990. Sulfiting agents; revocation of GRAS status for use on "fresh" potatoes served or sold unpackaged or unlabeled to consumers. Food & Drug Admin., Fed. Reg. 55: 9826–9833.
FDA. 1994. Sulfiting agents: withdrawal of regulation revoking Gras status for use on "fresh" potatoes served or sold unpackaged and unlabeled to consumers. Food & Drug Admin., Fed. Reg. 59: 65938–65939.
Feinberg, B., Olson, R.L., and Mullins, W.R. 1987. Prepeeled potatoes. In *Potato Processing*, 4th ed., W.F. Talburt and O. Smith (Ed.), p. 697–726. AVI-Van Nostrand Reinhold, New York.

Table 3—Factors affecting surface toughening of boiled abrasion-peeled potatoes treated with heated AA/CA solution and browning inhibitor dip

Expt	Potato	Treatment conditions	Treatment solution[a]	Browning inhibitor dip[b]	Other[c]	Boiled potato[d] Layer separation	Layer toughening
A	Russet	55°C/15 min	Std	None	–	Yes	Yes
			2% CA	None	–	Yes	Yes
			1% AA	None	–	Yes	No
			H_2O	None	–	No	No
B	Russet	55°C/15 min	H_2O	Std	–	Yes	Yes
				None	–	No	No
C	Round-white	55°C/15 min	Std.	None	–	Yes	Yes
		50°C/7 min	Std.	None		Yes	Yes (±)
D	Round-white	55°C/15 min	Std.	Std + 0.2% $CaCl_2$	–	Yes	Yes
				Std + 0.2% $CaCl_2$	Refrig.	No	No
E	Round-white	55°C/15 min	Std + 0.1% $CaCl_2$	Std + 0.1% $CaCl_2$	Refrig.	Yes	Yes
			Std	Std	Refrig.	No	No
F	Russet	55°C/15 min	Std + 0.1% $CaCl_2$	Std	Refrig.	No	Yes
		45°C/20 min	Std + 0.1% $CaCl_2$	Std	Refrig.	Slight	Yes
		45°C/20 min	Std	Std	Refrig.	No	No
		45°C/20 min	Std + 200 ppm EDTA	Std	Refrig.	No	No
	Round-white	55°C/15 min	Std + 0.1% $CaCl_2$	Std	Refrig.	No	Yes
		45°C/20 min	Std + 0.1% $CaCl_2$	Std	Refrig.	No	No
		45°C/20 min	Std	Std	Refrig.	No	No
		45°C/20 min	Std + 200 ppm EDTA	Std	Refrig.	No	No
G	Russet	45°C/20 min	Std	Std	Refrig.	No	No[e]
			Std + 200 ppm EDTA	Std	Refrig.	No	No[f]
	Round-white	45°C/20 min	Std	Std	Refrig.	No	No[f]
			Std + 200 ppm EDTA	Std	Refrig.	No	No[f]

[a] Std AA/CA soln = 1% AA + 2% CA. See Table 1, Footnote 1, for explanation of abbreviations.
[b] Std browning inhibitor dip = 4% AA + 1% CA + 1% SAPP; 5 min dip.
[c] Refrigerated for at least 1 day before boiling.
[d] Boiled 30 min.
[e] Difficult to mash.
[f] Easy to mash.

placed in the beaker as a spacer to prevent direct contact between potato surfaces and the beaker bottom (Expt. B). The severity of graying was least when direct contact of potatoes with the heated surface was prevented and greatest when direct contact was maximized. If discoloration were caused by an after-cooking darkening reaction between Fe and chlorogenic acid or nonenzymatic browning, more severe exposure to heat might be expected to increase the extent of darkening. In all subsequent trials, potatoes were stirred during treatment with the heated AA/CA solution, and the desiccator plate was used as a spacer to avoid over-heating.

Because of the possibility that bruising during handling might have been a source of graying, the severity of graying was examined in intentionally bruised potatoes (Expt. C). Graying was worse in tubers bruised after treatment with heated AA/CA solution than in tubers bruised before treatment. Presumably, treatment with heated AA/CA solution lowered the tendency of bruised potato tissue to undergo enzymatic browning in the same way that this treatment prevented browning of disrupted tissue at peeled surfaces.

Because storage temperature affects potato condition and composition (Smith, 1987), the influence of raw material storage on product graying was examined. The tendency of treated prepeeled potatoes to develop gray areas during storage appeared to be greater when the raw material was refrigerated prior to treatment. In a direct comparison of products from potatoes stored up to 4 wk at 4° or 20°C, the incidence and severity of graying were less with those stored at higher temperatures (Expt. D). Mondy et al. (1966) reported that Ontario and Pontiac potatoes stored at 10°C had significantly lower phenolic contents than did potatoes stored at 5°C. Katahdin potatoes, stored at 20°C, had a lower phenolic content than did potatoes stored at 5°C (Mondy et al., 1987). According to Smith (1987), storage of potatoes at higher temperatures would lower pH, due to formation and accumulation of organic acids, and would decrease or prevent darkening. Transferring potatoes from 2°C to 20°C was reported to increase their citric acid content. Weaver et al. (1978) found that storing potatoes for 3 wk at 20°C after 2 mo at 7°C significantly lowered the PPO activity. Thus, brief storage at 20°C in our study may have reduced the tendency of the potatoes to undergo after-cooking darkening or enzymatic browning. In subsequent experiments, potatoes were held at 20°C for short-term storage.

In other experiments, no relationship was seen between graying and extent of peeling (time in abrasion peeler), potato temperature when dipped in browning inhibitor solution, or completeness of draining following dipping.

Textural effects of heated AA/CA treatment

Examination of AA/CA-treated abrasion-peeled potatoes after boiling revealed the presence of a layer at the peeled surface, several mm thick, which, in some cases, was less tender than the underlying tissue. In severe cases, a shell-like layer of toughened tissue separated from the underlying tissue during handling and cutting, creating an unsightly product and interfering with mashing. In a series of experiments to understand and correct this deficiency (Table 3), we found that separation and toughening were associated with the presence of citric acid in heated treatment solutions (Expt. A). Potatoes, immersed only in hot water, would toughen if treated with an acidic browning inhibitor solution (Expt. B). Toughening could be reduced (although not eliminated) by using a lower heating temperature and shorter heating time (Expt. C). Refrigeration of treated potatoes for at least 1 day before cooking reduced their tendency to toughen (Expt. D). Toughening could be reduced by omission of $CaCl_2$ from treatment solutions and browning inhibitor dips (Expts. E). The greatest improvement was obtained by omitting $CaCl_2$ from treatment solution and reducing the treatment temperature to 45°C with the heating time increased to 20 min (Expt. F). Addition of EDTA to the treatment solution had no effect on layer separation or toughening (Expt. F) but appeared to improve the ease of mashing treated Russet potatoes (Expt. G).

The textural effects were probably due to activation of pectin methylesterase during treatment with heated AA/CA, resulting in an increase in free carboxyl groups of cell wall pectin and